Prince George Forest Region

Forest Resources & Practices Team

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FOREST RESEARCH NOTE

Ten Year Results of The Bear Mountain Mixedwood Trial (EP 1077): The Effect of Overtopping Aspen Canopies on White Spruce Seedling Growth and Seedling Microclimate

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Introduction

In a previous research note (Coopersmith and Hall 1999) we described the objectives and initial research findings of the Siphon Creek (Fort St. John) Installation of Experimental Project (EP) 1077. A second EP1077 installation, Bear Mountain, will be the focus of the present report.

The previous research note (PG-17) concentrated on the effects of overtopping aspen canopies on understorey spruce growth and yield, and proposed that a simple height to diameter ratio (HDR) could be a useful tool to evaluate the degree of overtopping by both broadleaf and herbaceous vegetation. HDR has been shown to be highly dynamic, reacting quickly to changes in the growth conditions experienced by white spruce (*Picea glauca*) seedlings, especially changes to their light environment. HDRs as low as 40 have been observed for well-established, open-grown 10-year-old spruce at Siphon Creek. These ratios rise quickly as competition for light increases. HDRs appear to have stabilised at or near 70 for white spruce saplings beneath trembling aspen (*Populus tremuloides*) cover at 5000 and 10,000 stems per hectare (sph) treatments at Siphon Creek (Coopersmith and Hall 1999). In this report we again compare height and diameter growth of white spruce seedlings beneath various densities of aspen cover to see if our 1998 research results at Siphon Creek are repeatable. In addition, we will examine in detail the effects of overtopping broadleaf canopies on the seedling microclimate of the underplanted spruce.

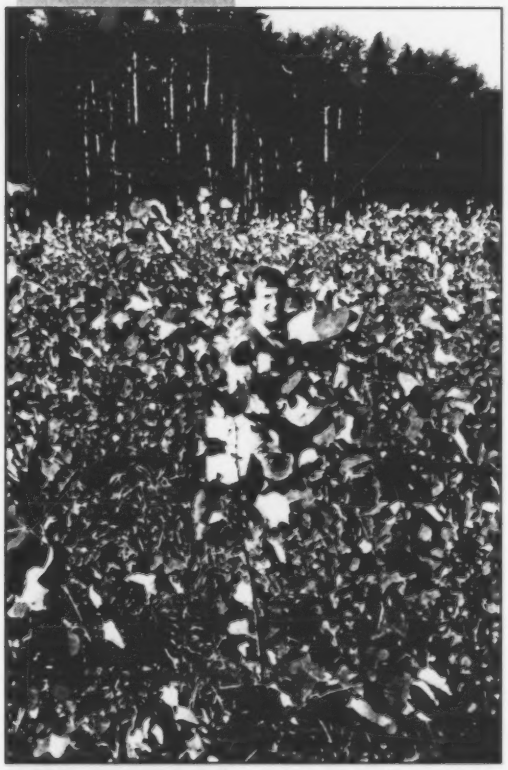

PHOTO 1. Summer student Tom Landine planting white spruce between thinned aspen at Bear Mountain. When this photo was taken (June 1990) the aspen sprouts were in their third season of growth and already more than two metres tall.

Overtopping broadleaf cover can affect understorey conifer crops directly, by limiting the amount of light for photosynthesis and shifting the ratio of red to far red light (Man and Lieffers 1997), and indirectly, by altering seedling microclimate (air temperature and humidity, soil temperature and soil moisture [Man and Lieffers 1997, 1999, Childs and Flint 1987]). These indirect effects can have both positive and negative affects on understorey conifers. Sheltering overstories of nurse crops can substantially reduce growing season frosts, especially so-called "radiative" frosts which occur on clear-sky nights (Stathers and Spittlehouse 1990). Such frosts occur frequently in areas of the Boreal White and Black Spruce (BWBS) biogeoclimatic zone during the growing season, and can cause substantial damage to young conifer plantations (Dang *et al.* 1992). Because they produce large amounts of leaves in less time than do conifers, broadleaf nurse crops can transpire substan-

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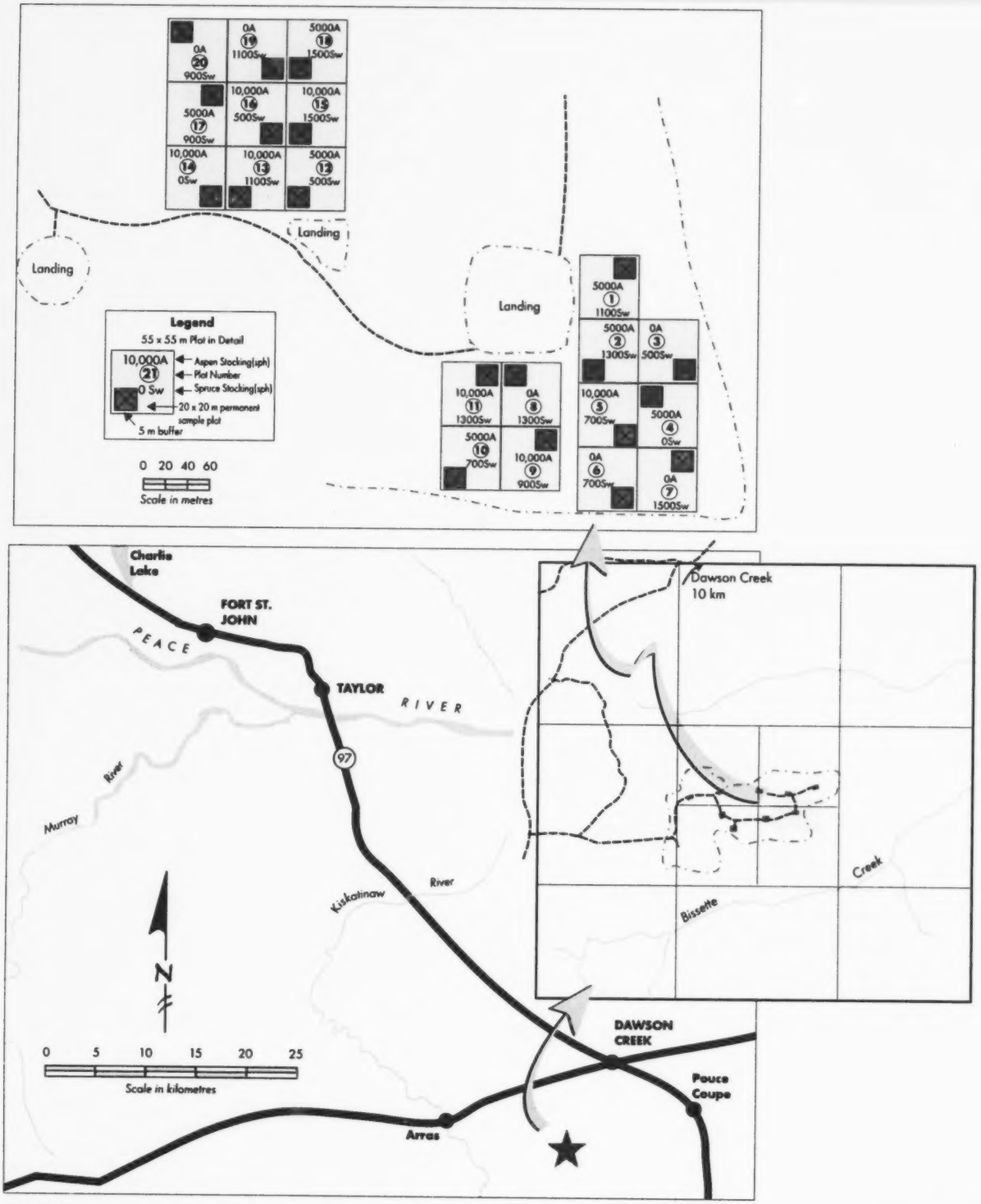
FIGURE 1. Location and layout of Bear Mountain installation of Experimental Project 1077. The study site is located approximately 15km south of Dawson Creek, within the Bear Mountain Community Forest. Logged in the winter of 1988, the study location was chosen in 1989. Installation began in 1990.



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tial amounts of moisture through their canopies early on in the rotation. This can be extremely important to young conifers, especially in the early spring when saturated soils can limit both above ground and below ground production. The drier soils beneath aspen canopies can also warm more quickly in the early spring than their saturated counterparts, thereby increasing productivity.

Materials and Methods

Site description and experimental design

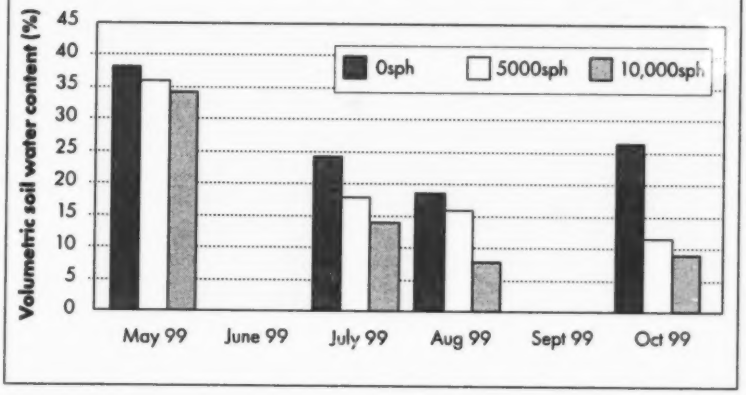
The Bear Mountain trial site is one of two mixedwood trials set up in the Peace River as part of the Experimental Project 1077 (The Autecology of Mixed Spruce-Aspen Stands, Crampton and Coopersmith, 1989). The site is located in the Dawson Creek Forest District approximately 15 km southwest of the city of Dawson Creek (55° 39' 14" N, 120° 20' 0" W, altitude 860 m, Figure 1). Although the study area is situated in the Peace variant of the moist warm subzone of the Boreal White and Black Spruce biogeoclimatic zone (BWBSmw1, Delong *et al.* 1990), it is close to the boundary of the wet cool subzone of the BWBS (BWBSwk1, Delong *et al.* 1990). The hygrotpe of the study area is mesic to subhygric, while the soils and understorey vegetation are indicative of a medium to rich nutrient regime. These characteristics are best described by a Spruce-Aspen—Step Moss (BWBSmw1/01, Delong *et al.* 1990) site series on the drier portions of the study site, and by a Spruce—Currant—Oak Fern (BWBSmw1/05, Delong *et al.* 1990) site series in the lower, wetter southeaster corner of the study site. The soils underlying the study area are fine textured Gray Luvisols typical of the Alcan-Buick map unit (Lord and Green 1986). There are substantial amounts of rock and stone in these soils, attesting to their morainal origin. These soils are characterized as moderately well drained with thick grey Ae horizons over a finer textured Bt horizon. The Bt horizons generally define the lower limits of the rooting zone in these northern boreal soils.

The Bear Mountain study area was logged in the winter of 1988. A dense stand of well-stocked young root suckers was observed on this site when it was first considered as a possible study area in the summer of 1989. Installation began in 1990.

The trial design consists of 20 plots, 55m by 55m in size (Figure 1). Each plot was subdivided into four 20m by 20m subplots. Each plot was randomly assigned an aspen target density of 0, 5000, or 10,000 stems per hectare (sph). In 1990 the plots were thinned to their respective densities. One subplot from each plot was then randomly assigned and under planted to a white spruce density of 0, 500, 700, 900, 1100, 1300, or 1500 sph. This 3 by 7 factorial design yields 21 plots, however the 0 aspen — 0 spruce plot is meaningless and was therefore not installed. Initially, only one subplot in each plot was planted in 1990. During the summer of 1991 and 1992 the remaining subplots were underplanted with spruce. As a result, all subplots contain 20 tagged and numbered spruce for measurement and observation.

Aspen was originally thinned using brush-saws. Inter-tree distances of 1m (10,000 sph) and 1.4m (5000 sph) were used as guides to conduct the thinning. In addition, all balsam poplar (*Populus balsamifera* L. spp. *balsamifera*), willow (*Salix* sp.), green alder (*Alnus crispa* (Aiton) Pursh spp. *crispa*), and paper birch (*Betula papyrifera* Marsh) were removed at the time of thinning. The 0 aspen plots were trimmed approximately every two years up to 1996 to maintain their open character. Some aspen, willow, balsam, and birch sprouting has occurred since the initial plot layouts. Additionally, some balsam poplar was mistakenly included in the initial plot layout due to the similarity of young aspen and balsam poplar stems. In 1998 the plots at Bear Mountain were "proofed" to their original design and density conditions by removing any re-sprouting birch, willow, alder, and balsam poplar that existed in the plots.

FIGURE 2. Bear Mountain, Summer 1999 TDR soil moisture plot means.



Microclimate Station Setup and Data Collection

Microclimate data were collected using a datalogger (Campbell Scientific Canada Corp., Edmonton Alberta, Model CR10). A multiplexer (Campbell Scientific, Model AM416) was used in conjunction with the datalogger to accommodate the large number of sensor inputs. The datalogger and multiplexer were housed in separate adjacent watertight boxes which were in turn covered by wooden boxes. These were centrally located with respect to the three plots to be monitored (0, 5000 and 10,000 sph plots, at the junction of plots 4, 5, and 7 respectively, Figure 1). The datalogger and the multiplexer were powered by a 12V deep discharge RV battery.

Air temperature and relative humidity were measured using a Vaisala, model HMP35C sensor (Vaisala Inc., Wolburn, Massachusetts) which combines a thermistor bead for air temperature with a capacitive relative humidity sensor. The Vaisala sensor was located in the 0 sph plot and housed in a Stevenson screen at a height of 1.7 m. Rainfall was measured using a tipping bucket rain gauge (Texas Electronics Inc., Dallas, Texas, Model TE525) mounted in the 0 sph plot.

Near ground (30 cm) air temperature was measured at one location in each of the 0, 5000 and 10,000 sph plots using twisted and soldered 30 AWG chromel-constantan (Omega Engineering Inc., Laval, Quebec) fine wire thermocouples. The fine wire thermocouples were mounted unshielded on wooden stakes. Three soil temperature sensors were installed at a depth of 5 cm beneath the organic/mineral soil interface in each plot. The soil temperature sensors consisted of twisted and soldered 24 AWG chromel-constantan (Omega Engineering) thermocouples potted in epoxy contained in brass tubing. All thermocouples were connected to the multiplex board and a reference temperature was obtained using a thermistor (Campbell Scientific, Model 107F) attached to the AM416 multiplex board.

Photosynthetically active radiation (PAR) was measured at 5 locations in each plot using a quantum sensor (Li-Cor Inc., Nebraska, Model LI-190-SZ) mounted at a height of 1.4 m. Sensor locations were chosen as representative of the plots and were a minimum of 5 m from the plot edges.

Volumetric and soil water content was monitored using single diode time domain reflectometer (TDR) probes. The probes consisted of three parallel 2.4 mm diameter, 20 cm long pieces of stainless steel welding rods mounted 1 cm apart using a flexible terminal strip. The probes were inserted vertically into the mineral soil to give an average water content of the upper 20 cm of mineral soil. Originally 4 probes were installed in each plot, however several probes were lost to trampling by horses who broke through the protective fencing around the research area in the early summer of 1999. Soil moisture measurements were made periodically by connecting a Moisture Point MP-917 Moisture Meter (G.S. Gabel Corporation, Victoria, BC) to the probes.

The data logger was programmed to record hourly averages of air temperature, relative humidity and PAR. Daily minimums, maximums and averages were recorded for air temperature, soil temperature and relative humidity. Daily totals of rainfall were recorded.

Beginning in the summer of 1999 light and leaf area index data (lai) were collected from 6 of the plots (plots 1, 2, and 4 for the 5000 sph areas and plots 5, 9 and 11 for the 10,000 sph treatments). Lai and light data were collected systematically from a series of gridpoints inside these plots. Lines of 5 grid points spaced 10 m apart were established at 5, 15, 25, 35, and 45 m along the east-west boundary of each plot and marked with numbered steel angle iron (25 grid points per plot). Light data was collected using two Li-Cor LAI-2000 Plant canopy analysers equipped with a LI-COR Leaf Area Index (lai) 2050 Optical Sensor (Li-Cor Inc., Nebraska). At each grid point, the tag number was entered into the LAI-2000 computer and the light measured at a point approximately 1 m above the steel angle iron. The machines were used with the 50% (half-circle) filters attached. One machine was used

PHOTO 2. Dave Coopersmith (standing with camera), Dave Crampton and summer student Jessica Harper installing the weather station network at Bear Mountain, May 1990. Crampton and Coopersmith designed and installed the mixedwood project at Bear Mountain.

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to take the west light readings, followed directly by the second machine taking the east light readings. Each machine was calibrated in full sunlight before the beginning and after the end of each set of 25 measurements in the middle of the nearest 0 aspen plot. Data sets from each machine were then combined to produce the lai and canopy transmittance data for each treatment. Light measurements were conducted between 10 a.m. and 2 p.m. on August 24, 1999.

The lai—2000 produces two useful measurements of below-canopy light environment. First, a leaf area index (lai) is calculated indirectly by measuring the steepness of light extinction curve from the vertical column of light. Second, diffuse non-intermittence (difn), or transmittance was measured by comparing the 0 aspen full sunlight levels to sunlight levels beneath canopies. Values range from 0 (no transmittance) to 1 (complete transmittance).

Aspen and Spruce Height and Diameter Measurements

Aspen and spruce height and diameter measurements were made in 1993, 1997, and 1999 following the cessation of height growth (not earlier than September 1st each year). A total of 1120 tagged aspen trees and 1440 tagged spruce seedlings were measured for diameter at breast height (1.3 m = dbh), root collar diameter (rcd for spruce only), tree height (ht), and height to live crown (htlc). Seedling vigour and health were assessed for each tree by dividing the stem into thirds and applying a system of coding for each third. Aspen heights were measured using the Canadian Forestry Equipment (CFE) cruising laser. Spruce height measurements were made using a silviculture tape.

Results

Trends in Aspen and Spruce Growth

Aspen and spruce height and diameter growth are summarised in Tables 1 through 8 and Figures 10 through 12, following.

The aspen at the Bear Mountain installation are now twelve years old. Much like the Siphon Creek installation, the Bear Mountain study area has seen the same severe problems with the fungal disease Shepherd's Crook (*Venturia macularis* (Fr) E. Muller & Arx.). This pathogen has attacked virtually every aspen at some point in the history of the trial and has produced top die back and height growth reductions. The net results of these attacks are trees that are heavily branched and crooked, and which have broad multi-topped crowns. However, despite these recurring attacks, the average heights of the aspen are now 6.5m and 6.3m, respectively for aspen densities of 5,000 sph and 10,000 sph (Figure 10, Table 1).

There are currently no significant differences in height growth between the aspen at 5,000 sph and 10,000 sph densities ($f = 1.223$, $p = .290$, Table 3). Similarly, there is no difference in aspen dbh at 5,000 sph and 10,000 sph densities ($f = 4.206$, $p = .068$, Table 3). However a p-value of 0.068 lies close to a probability of significance ($p = .05$), and would be significant at $\alpha = .10$.

The spruce understorey is now approximately 10 years old. For simplicity of analysis we will assume that all spruce at Bear Mountain are the same age. In reality however, many of the spruce are two years younger, since additional planting of the subplots and replacement of initial seedling mortality did not take place until 1991 and 1992. The spruce at Bear Mountain, especially those beneath the 5000 sph and 10,000 sph aspen covers have been heavily damaged by snowshoe hare browsing (*Lepus americanus* Erxleben). This damage was first observed in May of 1998, and resulted from a combination of high snowshoe hare populations that year and very little late winter snow cover. As a result, a large proportion of the leaders and laterals of the spruce were clipped. An average of 39.2% of the spruce seedlings in the 5,000 sph aspen plots and 62.5 % of the spruce seedlings in the 10,000 sph plots lost leaders and laterals to hare browse compared to only 2.92% seedlings browse in the 0 aspen plots (Table 6). The lower damage levels for the spruce in the 0 aspen plots can be attributed to the fact that the spruce in the 0 aspen plots were taller than spruce in either the 5000 or 10,000 sph plots (0.98 m for the fall 1997 spruce height in the 0 aspen plots vs. 0.77 m for 5,000 sph and 0.68 m in the 10,000 sph plots, Table 2). It was rare to find damaged seedlings that were taller than 90cm in any plot. This height appears to be the upper limit of browsing damage for the hares. The open grown spruce may have been tall enough to escape the majority of the hare browsing damage. Conversely, the lower browsing damage to the spruce in the 0 aspen plots may be explained by the avoidance of these open areas by the snowshoe hares. Hares tend to avoid areas without cover and prefer dense stands of aspen. This could also account for the higher levels of damage to the spruce beneath 10,000 sph aspen versus those in the 5000 sph plots. The most common form of damage was a loss of the top two year's growth, usually down to the 1997 internode, along with losses of some lateral branches. Trees that were clipped had to start their height growth from one of the residual internode buds

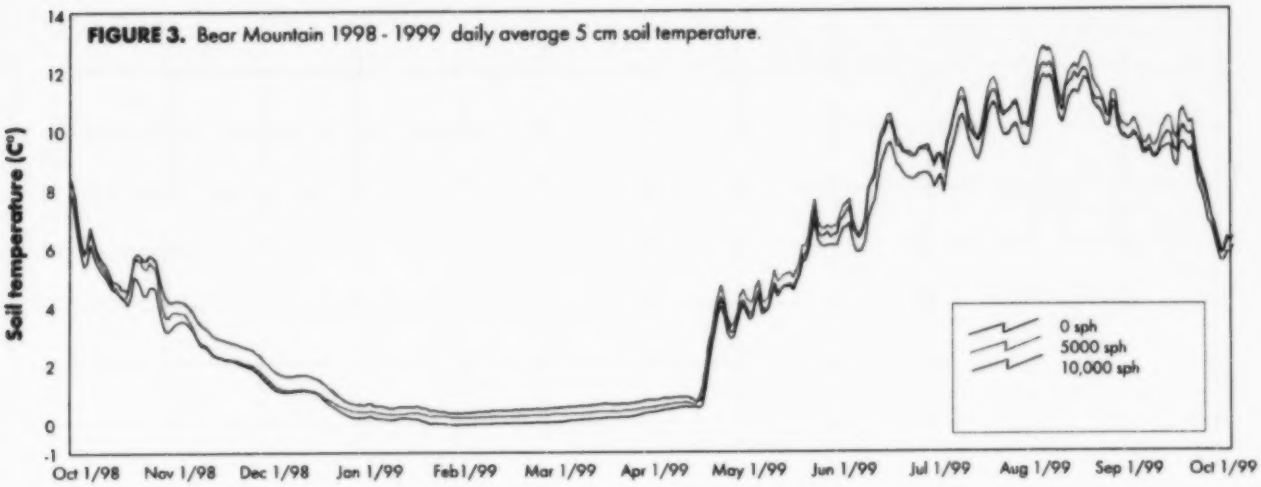

FIGURE 3. Bear Mountain 1998 - 1999 daily average 5 cm soil temperature.

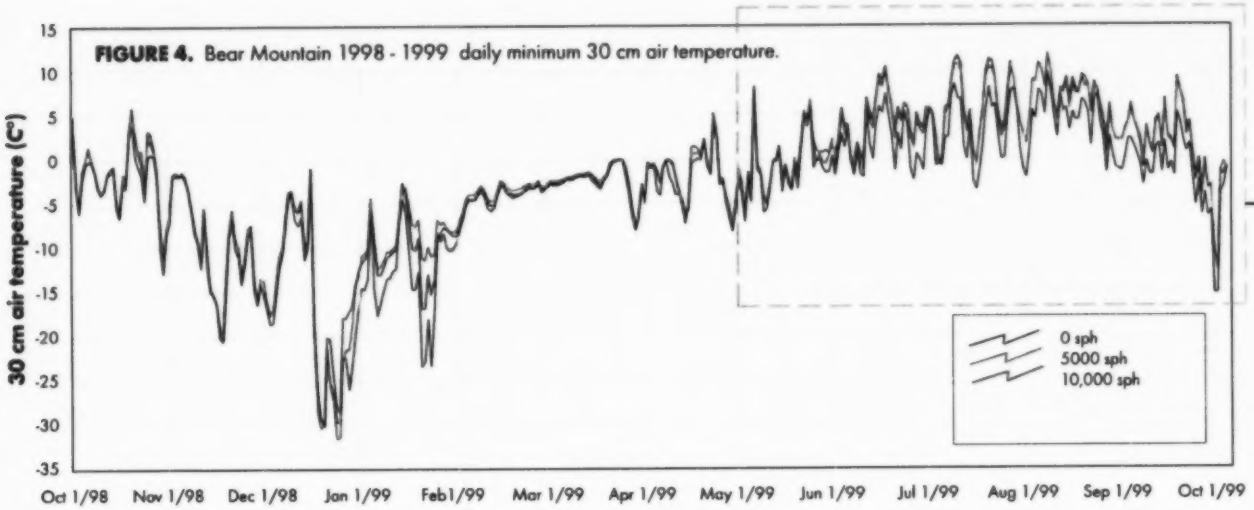

FIGURE 4. Bear Mountain 1998 - 1999 daily minimum 30 cm air temperature.

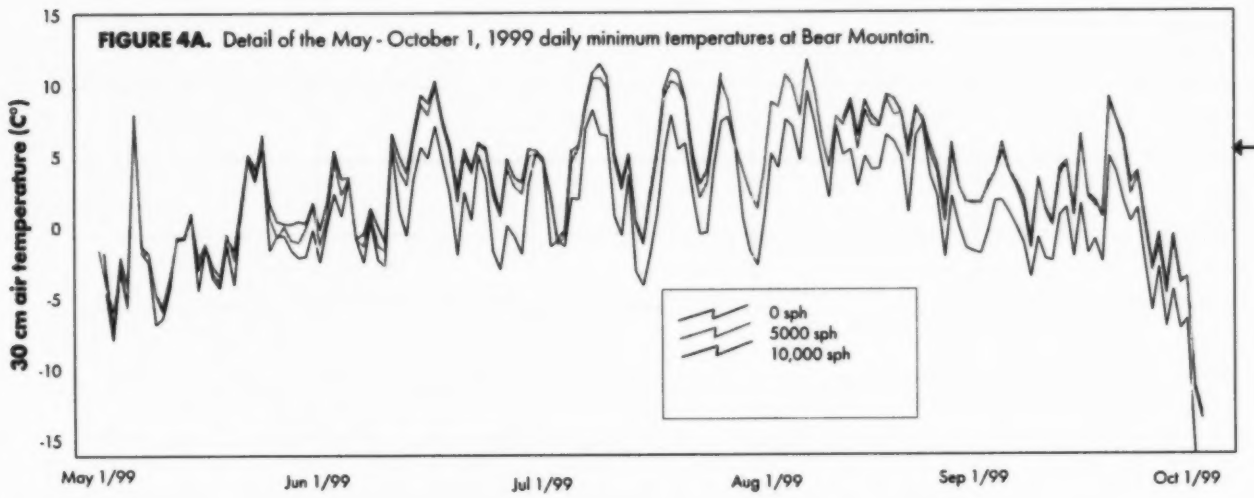

FIGURE 4A. Detail of the May - October 1, 1999 daily minimum temperatures at Bear Mountain.

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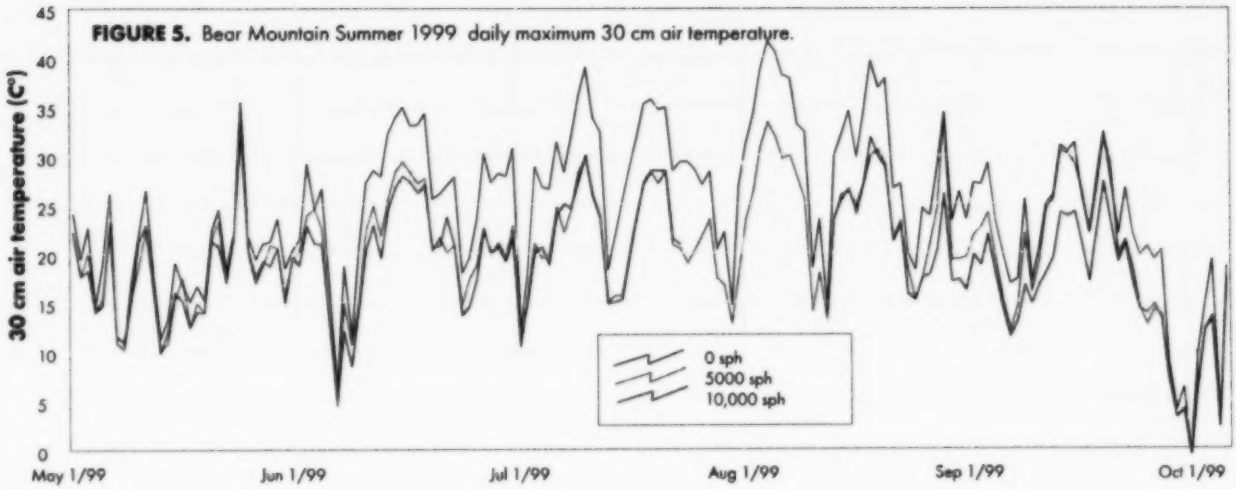

FIGURE 5. Bear Mountain Summer 1999 daily maximum 30 cm air temperature.

located along the undamaged stem or internode. The net result of the browsing has been a loss of two year's height growth for most of the spruce growing beneath aspen cover. The loss of two year's height growth also accounts for the drop in the calculated hdr for these plots between 1997 and 1999 (Table 2, Figure 12). We have always urged caution in the use of hdr values from damaged seedlings. Suitable trees would be those that were undamanged for three years prior to measurement.

The spruce trees in the 0 aspen plots are significantly taller ($f = 7.167$, $p = .007$, Table 4) in 1999 (1.48m, Table 2) than the spruce in either the 5000 sph aspen plots (0.85m, Table 2) or the 10,000 sph aspen plots (0.69m, Table 2). There was no significant difference in 1999 height for spruce beneath either aspen densities (Tukey's HSD Multiple Comparison of Means, Table 5). The significant differences between spruce height in the open versus beneath aspen cover make intuitive sense, and have only been exaggerated by the browsing damage to spruce beneath aspen cover. An examination of the partitioned sums of squares from the repeated measures analysis of variance (RMANOVA, Table 4) shows that 94.6% of the variation in the relationship of spruce height growth and year can be attributed to the significant linear component of the equations.

The strongly linear nature of height growth evident at Bear Mountain is in contrast to the non-linear relationships of diameter growth and calculated hdr. Height growth is less reactive to changing environmental conditions, especially light. This is especially clear if we examine data from our open grown trees. As these trees have emerged from the shrub and grass competition, their diameter growth has markedly increased and their hdr values have fallen. Most of the benefit of increased light (or conversely better nutrition or water balance associated with being larger and dominating greater ground area) is reflected in diameter, not height growth.

Similarly for root collar diameter, there was a significant effect of both year ($f = 327.32$, $p < 0.000$, Table 4) and aspen density ($f = 27.48$, $p < 0.000$, Table 4), as well as a significant year by aspen density interaction ($f = 55.33$, $p < 0.000$, Table 4). However, root collar diameter was less affected by snowshoe hare browse than was height growth. An examination of the graphs of change in rcd shows that the same constant relationship between year and changes in rcd (Figure 12) for all three aspen densities exists and we can again interpret the main effects of the model with confidence. This time, more than 98.5% of the partitioned sum of squares for the relationship of spruce rcd with time may be ascribed to the significant linear component of the RMANOVA (Table 4).

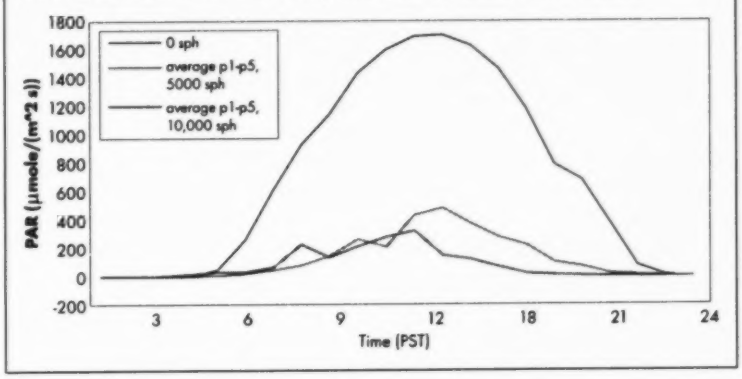

FIGURE 6. Bear Mountain 18 July 1998, hourly average PAR values.

Trends in HDR at Bear Mountain

The snowshoe hare browsing of spruce beneath aspen cover has complicated the trends in hdr development over time at the 3 aspen densities at Bear Mountain. This has resulted in lower than expected hdr values in these plots because smaller than expected values for top height are divided by larger root collar diameter values. The mean hdr values for spruce at all three aspen densities appear to have peaked in 1997 and are now decreasing. The mean hdr for open grown spruce peaked at 51.5 in 1997 and now has fallen to 47.1 (Table 2). Beneath 5000 sph of aspen, the mean hdr value was 67.7 in 1997 and 55.8 in 1999 (Table 2). At 10,000 sph of aspen, the mean hdr was very similar, 66.7 in 1997 and 53.1 in 1999 (Table 2).

The general decrease in spruce hdr across treatments should mean that growth conditions for the spruce are improving. In general, hdr falls because there is excess photosynthate available for diameter growth after the stronger sinks for root growth, needles, and new height growth have been satisfied. This is probably quite true for the open grown spruce in the 0 aspen plots. These trees are now 1.48m tall on average, with the tallest individuals now approaching 3m in height. These trees have now grown above direct shading and competition from herbaceous brush, woody shrubs and especially the very aggressive Canadian Bluejoint (*Calamagrostis canadensis*) which dominate this site series when aspen cover is removed. These trees are obviously doing well and their decreasing hdr values reflect this.

The spruce beneath the 5000 sph and 10,000 sph treatment areas, on the other hand, appear to be in poor condition. The browsing has set the growth of these trees back substantially, and has increased mortality in these plots by 3 and 4 times that of the 0 aspen plots respectively (Table 6). It will take several years for the spruce trees in these plots to recover from the 1998 browse damage. We expect additional mortality among these spruce trees, and eventually much higher hdr values among the survivors.

Height to diameter ratios were significantly affected by both aspen densities ($f = 10.731$, $p < 0.000$, Table 4) and year ($f = 50.268$, $p < 0.000$, Table 4). However, this story is complicated by a significant year by aspen density interaction ($f = 3.675$, $p = 0.015$, Table 4). An examination of the graphs of changes for hdr over time within the three aspen densities (Figure 12) shows that all three graphs have similar slopes and behaviours over time. With no obvious incompatibility between the graphs, we are able to interpret the main model effects. Interestingly, while the graphs for both rcd and height were strongly linear, those for hdr are strongly quadratic; accounting for more than 99.9 % of the variation in the partitioned sum of squares (Table 4).

The strongly quadratic nature of hdr reflects the fact that hdr encompasses both height and diameter in the calculation of its ratio. Even though height growth is linearly related to light levels, diameter growth is not. Their combination in hdr is quadratic.

Effect of Aspen Cover on Seedling Microclimate

Trends in Light Levels Beneath Aspen Cover

Calculated leaf area indexes (lai) in the 5000 sph plots were approximately half the values of the 10,000 sph plots (0.650 for the 5000 sph plots versus 1.237 for the 10,000 sph plots, Table 7). Similarly, much greater levels of light (difn or transmittance) penetrated the more diffuse canopy of the 5000 sph plots than did in the 10,000 sph plots. Nearly 75 % of the open plot radiation penetrated to 1 m in the 5000 sph ha plots compared to only 53.6 % in the 10,000 sph plots (Table 7). Although these differences in both measured lai and difn were not significantly different (lai, $f = 1.219$, $p = 0.275$; difn, $f = 1.6$, $p = 0.275$), this lack of significance is probably due to the small sample size ($n = 3$) than to lack of treatment effect. The small sample size leads to large standard deviations and little power to differentiate between treatment means. To try and counteract this small sample size effect, we plan on increasing the lai and difn measurements to all 14 plots with aspen canopies next year.

The levels of observed difn at Bear Mountain are high compared to other studies which have examined light and leaf area in similar stands. Comeau (1998) found transmittance levels as low as 9 and 34 % in 30-year-old stands of aspen on similar sites. We can therefore expect the leaf area of the aspen at Bear Mountain to continue to increase with time, and for the light levels beneath these canopies to continue to decrease.

Seasonal changes in bulk canopy transmissivity of light as a percentage of full sunlight can be seen for the 5000 and 10,000 sph plots in Figures 7 and 8 for 1998 and 1999. Light levels beneath aspen cover appear to decrease quickly in early May. From pre-leaf out light levels of between 70 % and 80 % full sunlight (a good measure of the effect of shading due to stems alone, since the aspen at Bear Mountain do not usually leaf out before May 15th) the light levels decreased quickly to be-

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tween 10 % and 30 % full sunlight by the middle of June. Transmissivity remained low beneath aspen cover until approximately the middle of August. Mid-season transmissivity was lower in the 10,000 sph treatments (approximately 10 % full sunlight) compared to the 5000 sph treatments (20 % full sunlight) for the same time period. Both light levels are extremely low, and well below the 40 to 60 percent full sunlight recommend by Man and Lieffers (1997) for full spruce height growth beneath aspen cover.

The daily effect of overtopping aspen on mid-season light levels can be seen in Figure 6. Light levels as high as 1702 µmoles/m^2/second were observed in the 0 sph plots at approximately 1 p.m. local standard time on July 18th 1998, a warm summer day with little or no cloud cover. These values compare to daily maximums of 481 µmoles/m^2/second at 1 p.m. for the 5000 sph plots, and 321 µmoles/m^2/second at 12 noon for the 10,000 sph plots.

Man and Lieffers (1997) have found that the compensation point (the light level above which positive net photosynthesis can occur) for open grown and "beneath canopy" white spruce seedlings varies between 50 and 80 µmoles/m^2/second. Likewise the saturation point (the light level above which no increase in photosynthesis is observed) for the spruce trees in their study was higher for open grown trees (1000 µmoles/m^2/second) than it was for seedlings beneath aspen cover (600 µmoles/m^2/second). If we take 80 µmoles/m^2/second as representative of the compensation point for our seedlings, and 600 µmoles/m^2/second as our saturation point, then light levels on July 18th in the 0 aspen plots are greater than the compensation point from approximately 6 a.m. to nearly 9 p.m. Light levels in the same plots exceed the saturation point from 7:30 a.m. to 6:30 p.m. In the 5000 sph plots, light exceeds the compensation point from 7:30 a.m. to 6:30 p.m. While in the 10,000 sph plots at Bear Mountain, light levels exceed 80 µmoles/m^2/second from 6:30 a.m. to approximately 3:30 p.m. Light levels never reach the saturation point beneath aspen cover at the Bear Mountain plots.

FIGURE 7. Bear Mountain 1998 Bulk Canopy Transmissivity.

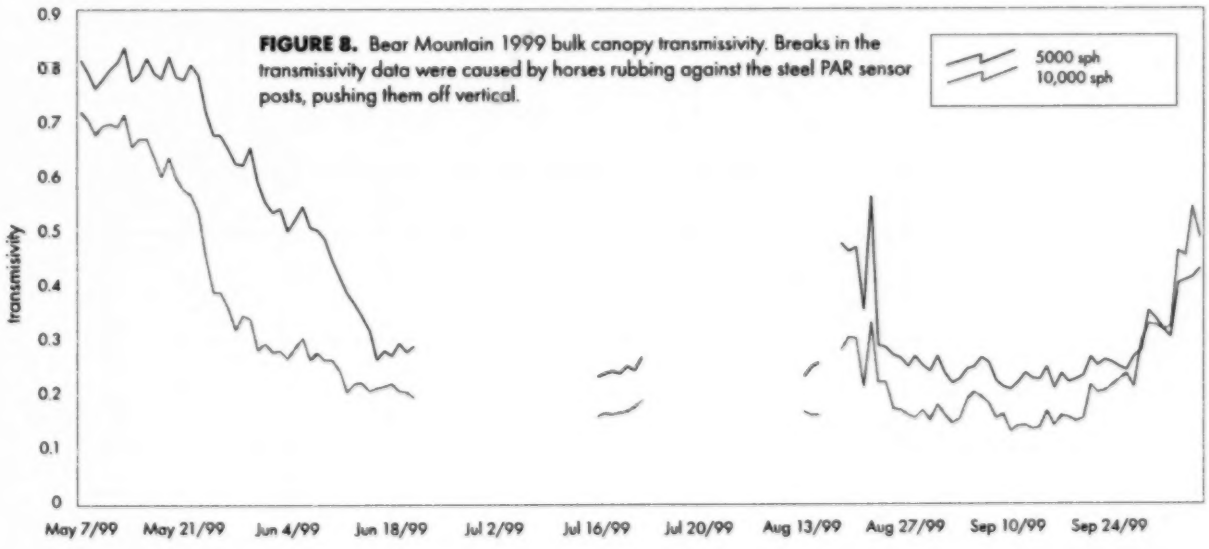

FIGURE 8. Bear Mountain 1999 bulk canopy transmissivity. Breaks in the transmissivity data were caused by horses rubbing against the steel PAR sensor posts, pushing them off vertical.

From a comparison of both transmissivity data and daily PAR values, it is clear that light levels beneath 5000 and 10,000 sph aspen canopies are already low, and will continue to drop even lower as both basal area and leaf area continue to increase.

Effect of Aspen Cover on Maximum and Minimum Air Temperatures

The most profound microclimate effect of overtopping aspen cover has to be the modulation of air temperatures beneath aspen canopies compared to air temperatures in the 0 aspen plots. In the open plots, daily minimum temperatures below 0°C were recorded on 27 days between June 15 and September 20, 1999 (Figure 4 and 5). Several of these daily minimums were severe enough to be categorised as a "hard" frosts. In particular, the −2.4°C frost event on June 26th , and the −3.5°C frost event of July 16th in the 0 aspen plots had the potential to cause damage to actively growing cambial tissue and occurred at a time when the trees were actively growing. The lowest daily minimum temperature recorded beneath aspen cover was a relatively mild −0.7°C, and this temperature occurred much later on in the summer, on September 8th.

The spring and summer of 1999 were exceptional for frosts in the Peace River. Despite this, we did not observe large numbers of frost damaged spruce in the 0 aspen plots. Newly planted conifers are certainly at greater risk from growing season frosts. However, this risk seams to be much reduced for older trees growing in the open.

The higher light levels in the 0 aspen plots also result in much higher daily maximum air temperatures at 30 cm compared to study plots with aspen. In the 0 aspen plots, daily maximum temperatures above 30°C were recorded on 39 days between June 15th and September 20th (Figure 5). Fourteen of these days had daily maximum temperatures above 35°C, and the yearly maximum temperatures on August 1st and 2nd reached 41.7 and 40.6°C respectively. By comparison, beneath aspen cover, maximum daily air temperatures went above 35°C only once , and above 30°C only 6 times during the same time period. Clearly, overtopping aspen cover does a great deal to moderate the air temperature of the seedling microclimate compared to the open plots without aspen cover.

Effect of Aspen Cover on Soil Temperatures

The primary concern with soil temperatures in the BWBS is cold soils, especially in the early spring. Cold soils can limit belowground processes, especially the production of fine roots, and can also slow the osmotic flow of water to roots. Both these processes can lead to damage in seedlings in the early spring, especially if the they occur after the trees have burst their buds and are actively transpiring.

We have observed relatively small differences in average 5 cm soil temperatures between the three aspen treatments at Bear Mountain (Figure 3). In general, mean temperature differences between the 3 treatments were usually less than 1 °C between July 10th 1998 and September 1st 1999. It appears as if the 0 sph and 5000 sph treatments were slightly warmer than the 10,000 sph treatments over this time period (especially in the summer months), but again, these differences are small.

Soil temperatures start to increase by the middle of April at Bear Mountain, probably corresponding to the time that snow cover leaves these plots. This is well

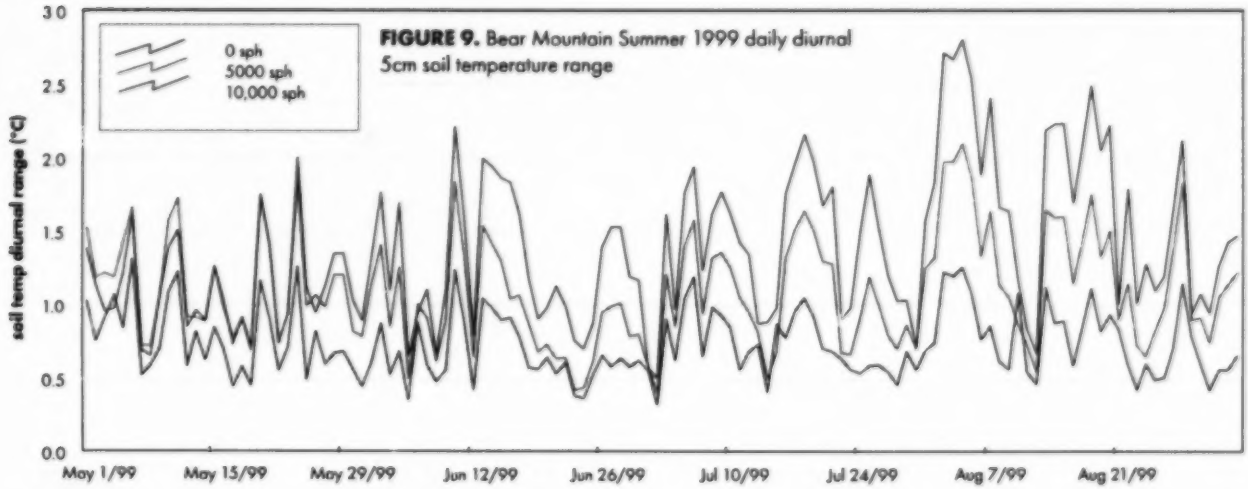

FIGURE 9. Bear Mountain Summer 1999 daily diurnal 5cm soil temperature range

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before the time of bud flush in the aspen, which typically takes place some time around May 15th. Average soil temperatures at 5 cm soil depth vary between 5 °C and 13 °C during the period that aspen leaves are present (May 15th to September 15th). It would appear that soil temperatures are quite adequate for tree growth during this time period.

Örlander *et al.* (1990) found optimum root and shoot growth occurred in Norway spruce (*Picea abies*) at soil temperatures of approximately 25°C. Optimum soil temperatures for Scots pine (*Pinus sylvestris*) were even warmer, approaching 30°C. Root production in both species was affected by low soil temperatures. Below-ground productivity was very low at and below 5°C. Between 10°C and 15°C, below-ground productivity was at least half of the levels observed at warmer optimum soil temperatures.

Soil temperatures start to drop steadily after September 15th, reaching their yearly minimum of between 0 and 1 °C around January 1st. It is interesting to note that the soils at Bear Mountain do not freeze in the winter, despite yearly minimum air temperatures that can reach −50 °C. The substantial snow cover present in these plots insulates the soils from very low temperatures.

Although there is little difference in mean soil temperatures with aspen treatments, we observed much greater diurnal soil temperature fluctuation in the 0 and 5000 sph aspen treatments than we did in the 10,000 sph plots (Figure 9). Daily temperatures fluctuations of at least 1.5 °C were observed 50 times in the 0 sph treatment plots between May 1st and September 1st 1999. During the same time period, the same range of temperature fluctuation was observed 23 times in the 5000 sph plots, but not once in the 10,000 sph plots. The yearly maximum diurnal soil temperature fluctuations occurred in the 0 sph plots on August 4th 1999. At 2.8 °C, this diurnal change was 0.7 °C greater than the largest fluctuation in the 5000 sph treatments (2.1 °C, August 4th), and nearly double the largest fluctuation observed in the 10,000 sph plots (3 measurements of 1.6 °C, on May 6th and 24th, and again on August 4th).

Effect of Aspen Cover on Soil Moisture

Broadleaf tree species such as trembling aspen can have high leaf areas. These canopies can effect soil moisture directly, through the transpiration of large volumes of water during photosynthesis, and indirectly by intercepting precipitation before it reaches the soil surface (Oke 1987). These effects can be both beneficial and detrimental to understorey conifers. The reduction of excess soil moisture can be beneficial to understorey crops if soils are saturated and cold in the early spring. Conversely, broadleaf canopies can also reduce the water available to understorey conifers during warm summer periods. This can induce summer drought stress that can limit photosynthesis in understorey conifers.

There were marked seasonal differences in the observed moisture levels in the soils of the 3 treatment areas (Figure 2). Although the 0 sph treatments had the highest observed levels of soil moisture in May 1999 (38.2% versus 35.9% for the 5000 sph and 34.2% for the 10,000 sph treatments) the differences between treatments were small. However, by July, much greater treatment differences had developed. By July, the soil moisture levels in the 5000 and 10,000 sph treatments at Bear Mountain were much lower (17.8 % and 13.9 % respectively) than the moisture levels in 0 aspen plots (24.3 %), and they remained low in these latter two treatment units right up to October (11.4 % and 9.0 %). By comparison, the 0 aspen plots reached their minimum soil moisture level in August (18.6%), and had begun to rewet by October. This is probably indicative of the continued aspen transpiration on the 5000 and 10,000 sph into the late summer, as well as interception of fall precipitation by aspen canopies in these plots.

Summary

- The trends in height and diameter growth and calculated hdr values of open grown spruce trees are very similar for both Bear Mountain and Siphon Creek research installations. HDR values less than 50 appear to be indicative of a well established spruce tree in the BWBS zone of the Peace River.
- We observed much greater levels of snowshoe hare damage beneath aspen cover compared with open grown seedlings. Because their height growth will be slower in mixedwood stands, spruce trees growing beneath aspen cover will be at greater risk from cyclical snowshoe hare browsing damage than are open grown spruce trees. Damage from snowshoe hares at the Bear Mountain site decreases once seedlings reach top heights of approximately 90 cm.
- Aspen cover has a substantial effect on seedling microclimate. Compared to open grown seedlings, young spruce trees less than 1 m tall growing beneath aspen cover are exposed to much less frequent frost events, and the frost events that do occur are less severe. Soils beneath aspen cover are substantially drier throughout much of the grow-

ing season. And although soils beneath mixedwood stands appear to have smaller diurnal temperature fluctuations compared with soils in open stands, these diurnal fluctuations do not result in substantially warmer soils for open stands. Plots with and without aspen appear to have adequate soil temperatures by the start of the growing season.

- Observed light levels beneath aspen canopies at Bear Mountain are now well below expected optimums for spruce growth. Even though the trembling aspen at Bear Mountain are only 10 years old, light levels are between 10 % and 20 % of full sunlight. As the basal area and leaf areas of aspen in these stands will continue to develop for many years to come, we can expect these light levels in the understorey to continue to decrease, and the performance of the planted spruce trees beneath aspen cover to continue to deteriorate. Some additional thinning of aspen may be necessary to maintain adequate spruce growth.

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